them are 4 or 5 miles away. All are obviously located close to land which could be cultivated by flood irrigation if there were enough water and if the inhabitants could have a permanent supply to drink. The case is only one of hundreds scattered all over New Mexico and Arizona. It seems inexplicable on the theory of climatic uniformity, but perfectly reasonable if the climate of the past was different from that of the present.

(To be continued.)

SOME RECENT OBSERVATIONS AND THEORIES ON THE STRUCTURE AND MOVEMENT OF GLACIERS OF THE ALPINE TYPE.

By ALAN G. OGILVIE.

Glaciers are of perennial interest alike to mountaineers and to physical geographers. Every mountaineer must have asked himself why the crevasses cut the ice-mass in one general direction at one part and quite otherwise in another; what are the causes of the banded appearance and of the granular character of the ice; and how it comes that a streak of moraine starts, with no apparent cause, at some point of the surface and grows broader and thicker as it passes down to join the great shoot of gravel and boulders where the ice ends. Students of physical geography have not yet agreed as to the *rôle* played by glaciers in the development of terrestrial relief. Is the glacier an active agent of erosion, or is it not? and if it is, what is its mechanism as a tool of erosion?

On all such questions much light has been thrown by some recent observations and theories with regard to the internal structure of the ice of glaciers of the Alpine type, as well as to the details of glacier movement and its relation to the transport of moraine matter.

The chief object of the present paper is to give some account of the work of the observers who have of late made important additions to our knowledge of these matters. At the same time it will be of advantage to review briefly the general features of alpine glaciers. Indeed, the convenience of introducing thus the technical terms which have to be employed in the later part of the paper is sufficient reason for giving here a summary which must be marked by the defects that are unavoidable in a condensed statement of so large a subject.

The glacier consists of the *névé*, or collecting area, and the tongue, or area of melting or ablation. To these H. F. Reid has applied the names "reservoir" and "dissipator." The boundary where the one passes into the other is called the "*névé* line." The whole glacier lies upon an inclined bed, and in the bigger glaciers the *névé* generally occupies a wide basin while the dissipator lies in a narrow valley.

If, in any given time, the quantity of snow accumulating on the *névé* is equal to the amount of ice which passes the *névé* line, and this in turn is equal to the quantity of ice which is melted in the dissipator, the glacier is said to be in equilibrium, and, so far as its dimensions are concerned, it is "stationary." In this stationary condition of the glacier, its "front" or "snout"—the termination of the dissipator—neither advances nor retreats. In such a glacier the surface of the *névé* remains at a constant level, and each fresh addition of snow on the surface is followed by a downwards motion of the ice which has been formed by previous accumulation. The upper surface of the fresh snow in the *névé* is melted by the sun's rays. The water sinks in for some distance, until it freezes, when it unites several snow crystals so as to form granules of ice. The snow thus becomes gradually more and more compact, till at last it is entirely changed into a translucent mass of ice.

The process which follows is not well understood, but it is certain that the grained structure—to which we must return—remains throughout the entire length of the glacier, and that the granules, of which each is a single crystal, grow until, at the glacier front, they are often as large as a hen's egg; there indeed a freshly broken surface often has an almost nodular appearance.

The *névé* shows a well-marked stratification wherever the crevasses permit sections of it to be seen. As a general rule each bed of the strata corresponds to a single snowfall, while thin bands of fine wind-borne dust, which frequently separate the layers, represent periods of dry weather. Whether the dust layer be present or not, the crystalline surfaces of each bed are more or less plane,

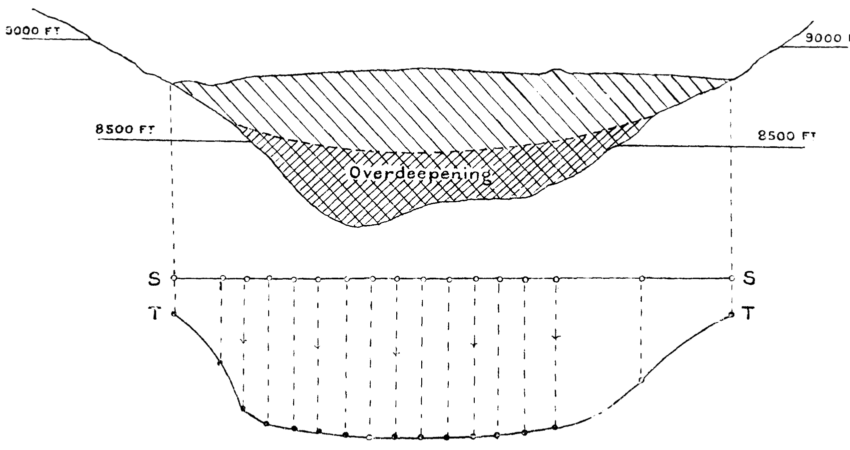

FIG. 1.
(After Hess, 'Die Gletscher.')

although inside these surfaces, and throughout the bed, the crystals are interlocked in the most irregular way.

Observations taken over many years have shown that the average rate of motion in various glaciers of the Alps lies between 100 and 500 feet per annum. In the dissipator the surface velocity is unequally distributed, the centre moving faster than the edges. This variation depends upon the breadth, the depth, and the shape of the cross-section, as well as upon the slope of the glacier bed. This is well illustrated in Fig. 1. The curved line TT represents the deformation produced upon a line of stones which was originally a straight line, SS, across the glacier. It will be noticed that the critical points of the curve are exactly above the ledges of the "overdeepened" part of the valley. This proves that the surface velocity is greater where the ice is deeper.

The deformation of the surface ice, like that of the line of stones, is greatest between the critical points and the edges of the glacier. By taking the average of all observations of this sort, Hess found that the proportion of maximum to minimum velocities in one line of stones was as 100 to 78.

In the dissipator, towards the glacier front, there is a striking decrease of velocity even when the slope of the glacier bed is not diminished there. This, according to S. Finsterwalder, is due to the decrease in the thickness of the ice in this part which is produced by ablation.

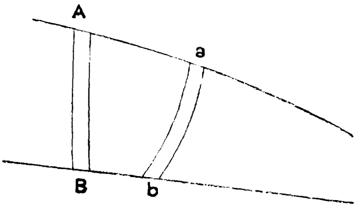

FIG. 2.

The velocity decreases from the surface of the ice towards the rock bed, the lower portion being retarded by friction. Thus there exists not only a horizontal deformation (see Fig. 1), but also a vertical deformation. In Fig. 2, which represents a longitudinal section in the glacier tongue, a column of ice, AB, undergoes deformation while moving to the position *a b*.

The Crevasses.—Considerable light is thrown upon the physical properties and upon the structure of the ice by the crevasses. The lack of elasticity which produces them shows that glacier ice cannot be satisfactorily compared to a flowing liquid.

The maximum horizontal deformation in the tongue, as we have seen, takes place near the edges. The ice here undergoes a tension produced in the direction indicated by the deformed lines of stones. When this tension exceeds a certain limit, the ice gives way and "lateral crevasses" are formed, which have a direction perpendicular to the tension (see Fig. 3). Except at the extreme

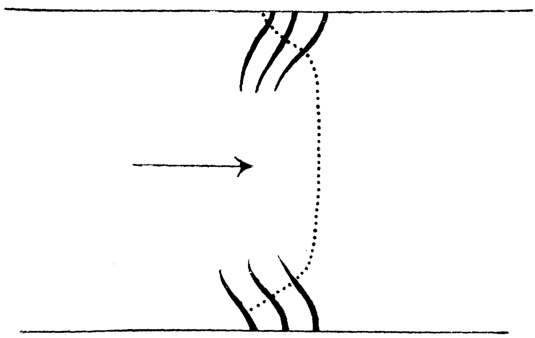
FIG. 3.

edges, these crevasses rarely extend farther into the body of the ice than one-third of the depth of the glacier, and it is considered possible that below this point the ice is more elastic.

As the glacier passes over a step, or rapid fall, in the bed, the ice-mass becomes bent so that the surface is convex, and a longitudinal tension is produced. Enormous "transverse" crevasses open, often extending right across the glacier (see Fig. 4). Below the step the surface becomes concave, the crevasses close up by regelation—though their marks remain—while it is possible that transverse "ground" crevasses open on the under surface of the ice. If the step is very steep, the transverse crevasses formed at its upper part may reach right through to the bed, so that great slices of ice are broken off and slide slowly down vertically to the lower level.

Where the glacier widens, as it often does at its foot, the lateral compression is relaxed, and the spreading of the ice causes a tension outwards from the centre line to the sides of the glacier. As a consequence, "longitudinal" crevasses are formed wherever the glacier broadens.

In the *névé*, irregular crevasses are produced by changes in slope which are very frequent in this region. These crevasses are generally narrow at the surface, widening downwards and then gradually narrowing in their lowest parts.

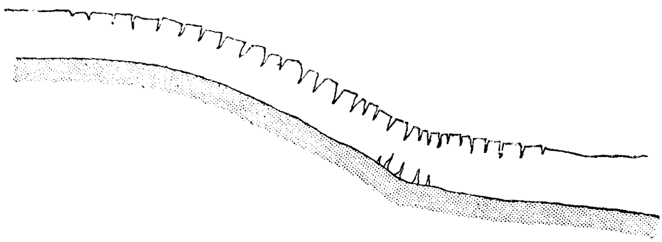

FIG. 4.

Hans Crammer has explained this phenomenon by attributing its formation to a series of snow bridges which have formed, year after year, over a widening crevasse, and which have themselves been broken each year by tension.

In Fig. 5 the thick line represents the *névé* surface when the crevasse began to open: *a, b, c, d, e,* represent the beds which have formed snow bridges in successive years.

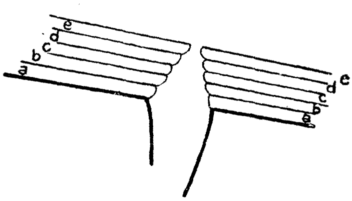

FIG. 5.

Round the upper side of the reservoir, and roughly parallel to it, there runs a long irregular crevasse—a natural moat for which no specific term exists in English—the "Bergschrund" or "Rimaye." The snow or ice slope above this crevasse and nearer to the walls of the "cirque," is always much steeper than the *névé* surface below it. The Bergschrund, in fact, marks the line where the real downward motion of the *névé* begins; the frozen matter above adheres to the walls of the cirque.

The Line of Flow in the Glacier.—The idea of a flowing motion of the glacier is far from new, having been suggested in 1773 by Bordier, and associated later with the names of Forbes, Tyndall, and others. In recent years it has been much developed and elaborated independently by S. Finsterwalder and H. F. Reid. The theory * may be briefly stated as follows :—

The ice is regarded as an incompressible mass. Each particle of snow which falls upon the *névé*, after being converted into ice, begins to follow a definite course in the interior of the glacier. It eventually emerges at a definite point on the surface of the dissipator.

Thus all the points of entrance in the reservoir may be joined to corresponding points of exit in the dissipator by lines of flow in the interior. A horizontal projection of these lines is given in Fig. 6, while Fig. 7 shows a longitudinal section, exaggerated vertically, both the lines of flow and the planes of stratification being indicated. It will be noticed that those lines of flow which begin at the margin of the *névé* run along the base of the glacier and emerge at the margin of the tongue; those which start from other points on the surface of the

* A model constructed, under the direction of the author of this paper, to illustrate this theory has been placed in the Science Museum, South Kensington.

reservoir pass inwards there at definite angles, and terminate by reaching corresponding points in the surface of the dissipator. In the *névé* the strata have more gentle slopes than the flow lines, while in the tongue the reverse is the case.

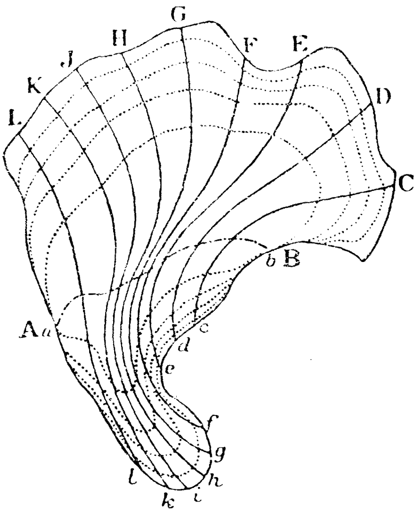

Fig. 6.

Aa — - — - — - — - bB = *Névé* line.
as Hh = Lines of flow.
.... = Lines dividing the glacier into areas of equal accumulation and ablation.

(After Finsterwalder, 'Zeitschrift des D.U.Ö. Alpenvereins Wissenschaftliche Ergänzungshefte,' vol. 1, No. 1.)

The Structure of the Ice.—Wherever the glacier enters a narrow valley it is subjected to immense lateral pressure. This fact coupled with the kind of movement just mentioned is sufficient, according to Hess, to explain the gradual transition of the strata from their almost horizontal position in the *névé* into a spoon-shaped form in the tongue. Hess believes that such a form is indicated by the observations which can be made at the surface, and in illustration of the changes of form which he describes he has carried out most interesting experiments in which he squeezed stratified wax out of a narrow opening in a cylindrical reservoir.

This leads us to the consideration of the observations made many years ago upon the structure of the glacier tongue — ("veined structure," "structure rubanée," "Bänderung," "Blätterung"). In the upper part of the dissipator, the ice appears to be striped, in a longitudinal direction, with alternate bluish and white bands or veins. The difference of colour is due to a greater amount of air being imprisoned in some bands—the white—than in others—the blue.

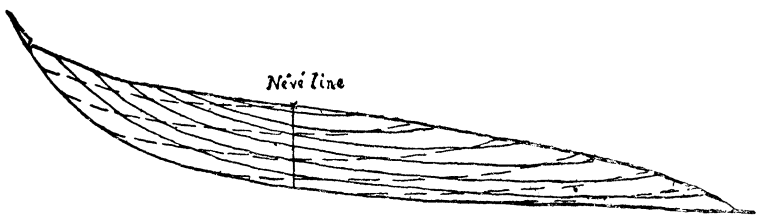

Fig. 7.

— — — — — = Stratification lines.
—— Lines of flow.

(After H. F. Reid, 'Appalachia,' vol. 11, 1905–08.)

In lateral and transverse crevasses these veins may be traced into the interior of the ice, and it is easy to observe that at the edges of the dissipator they dip roughly parallel to the bed of the glacier, while towards the centre they become more and more vertical. In the lower part of the tongue the veins cease to crop out in this manner and commence to cut the surface in great arcs pointing down-stream.

This observation led Agassiz to construct sections of simple and composite glaciers to show the forms produced by the lateral pressure (see Fig. 8). These forms are very similar to those which resulted from the wax experiments of Hess.

The view of Agassiz that the veined structure is simply the stratification transformed, has been accepted by most glaciologists, but it should be noted that Prof. Forel is among those who do not accept it.

Recent Observations on the Veined Structure. — Much supplementary data has been collected with reference to the manner of this transition. On the glaciers of Forno, near the Maloja, and Unteraar, in the Bernese Oberland, H. F. Reid followed the veined structure up-stream until its identity with the stratification was undoubted; and the Glacier Congress of 1905 emphatically expressed the opinion that the veined structure has its origin in the stratification.

A most interesting series of observations made by Hans Crammer on the glaciers of the Eastern Alps, and especially on the Marzellferner and the Obersulzbach glacier, have led him to the same conclusion.

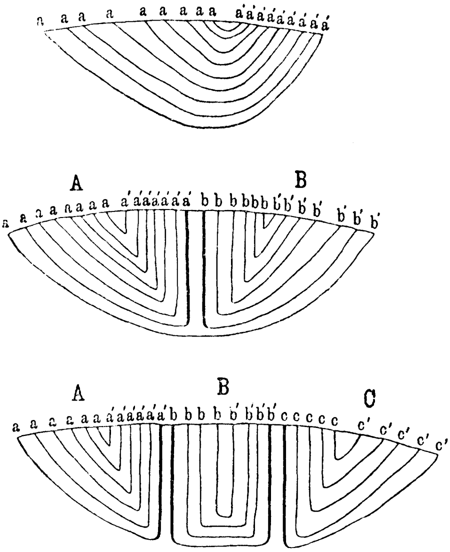

FIG. 8.
Agassiz, "Système Glaciaire."

Since Crammer has based an important theory upon his observations, it will be useful to follow his account of the phenomena which he saw under particularly favourable circumstances; for it so happens that in the glaciers upon which he worked, and especially in that of the Obersulzbach, great transverse crevasses permit the structure to be examined exactly at the point where the wide reservoir narrows to form the root of the tongue.

Some distance above this point, the *névé* strata were observed in the crevasses to have an undulating form, the axes of the undulations running in the direction of flow. A little farther down-stream these undulations were seen to have become well-marked folds. Moreover, ablation—which removes more and more of the surface ice as the glacier passes down the valley—was at work here; thus the surface of the glacier cut the anticlines and synclines of the folds so that their outcrops formed great arcs pointing up-stream and down-stream respectively. Still farther down-stream the folds become sharper and the arcs of outcrop more elongated. Folds similar to these were recognized in the Rhone glacier by the Glacier Congress of 1899, and a series of long ridges and furrows on the surface—the effect of ablation upon the folds—were given the name "Reid ridges." Finally, the two limbs of each fold, as well as those of the surface arcs after being squeezed closer and closer together, were observed to coincide, and to produce a single vein or band. These bands as seen on the crevasse walls were vertical in the centre of the glacier and more inclined near the edge. The appearance of their outcrop on the glacier surface was exactly that of the veins already recognized as running parallel to the direction of flow

A close examination of the veins showed that they were not continuous bands, but were composed of a great number of lenticular "leaves" ("Blätter" of Crammer) which overlap, the one on the other (Fig. 9).

FIG. 9.

These observations on the origin of the veined structure led Crammer to the conclusion that their disposition in the interior of the tongue is not such as is shown in Fig. 8, but that they have in reality the form of a fan (Fig. 10).

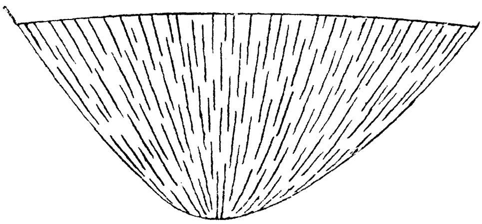

FIG. 10.

(After H. Crammer, 'Mitteilungen der Geographischen Gesellschaft,' Munich, vol. 4, 1909.)

In the glacier foot of the Marzellferner, which had retreated recently within a narrow valley, Crammer was able to see a section of this sort. But this is an exceptional case, and in most glaciers the veined structure appears in the foot in a spoon-shaped form. Such glaciers, according to Crammer, have room to spread at their foot, and are either stationary or advancing; only in a retreating glacier, such as the Marzellferner, where a part which has not spread has become the front, does the veined structure there show in a fan-shaped form. The spoon form of the veined structure, as seen in plan, is shown in Fig. 11, and its longitudinal section, which can be seen in the terminal longitudinal crevasses, in Fig. 12.

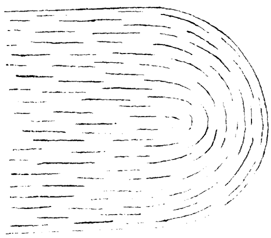

FIG. 11.

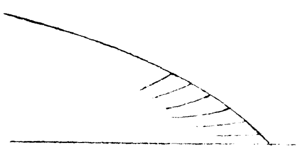

FIG. 12.

(After H. Crammer, 'Mitteilungen der Geographischen Gesellschaft,' Munich, vol. 4, 1909.)

This explanation of the veined structure may be applied to sections of a composite glacier: Fig. 13 for comparison with Fig. 8.

The explanation given by Crammer of the change produced upon the structure, in glaciers which have a wide reservoir and a narrow dissipator, is as follows:—

The rock bed of the reservoir is basin-shaped, and narrows down-stream. Thus a bed of *névé*, flat when it is formed by snowfall, comes to occupy a less extensive area as it gets overlaid and sinks, and as it passes from the broad upper basin to the narrowing part, towards the *névé* line. The bed of *névé* is compressed from side to side by lateral pressure, which reduces its area by throwing it into folds with their axes at right angles to the pressure, *i.e.* in the direction of flow. The greatest amount of folding takes place at the base of the mass and where the narrowing of the bed is most marked, generally about the *névé* line.

This theory is clearly illustrated in Figs. 14 and 15. Fig. 14 shows a glacier divided so as to show successive cross-sections: Fig. 15 is a cross-section cut at the *névé* line.

One of the arguments which have been brought against the theory that the veined structure has its origin in the stratification, is that bands lying nearly horizontal have been seen in crevasse walls to cut the vertical veining, and that the two types represent the stratification and the veining present together.

Reid has declared these horizontal bands to be reclosed crevasses, and Crammer gives a similar explanation, thus :—

When the glacier passes over a steep step in the valley the transverse crevasses which opened on the convex surface of the ice become vertical planes of shearing which reach to the bottom. Immediately below the step, these shear planes or their scars are vertical, and crop out in straight transverse lines. Differences of velocity, however, soon cause them to undergo a

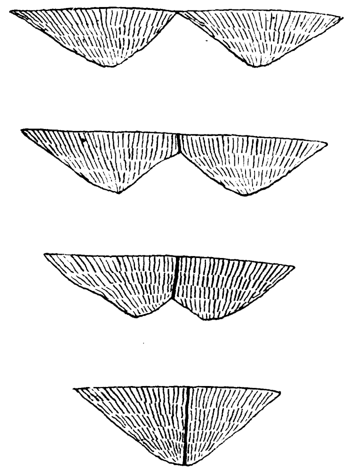

FIG. 13.

(After H. Crammer, 'Neues Jahrbuch für Mineralogie,' etc., vol. 18, 1904.)

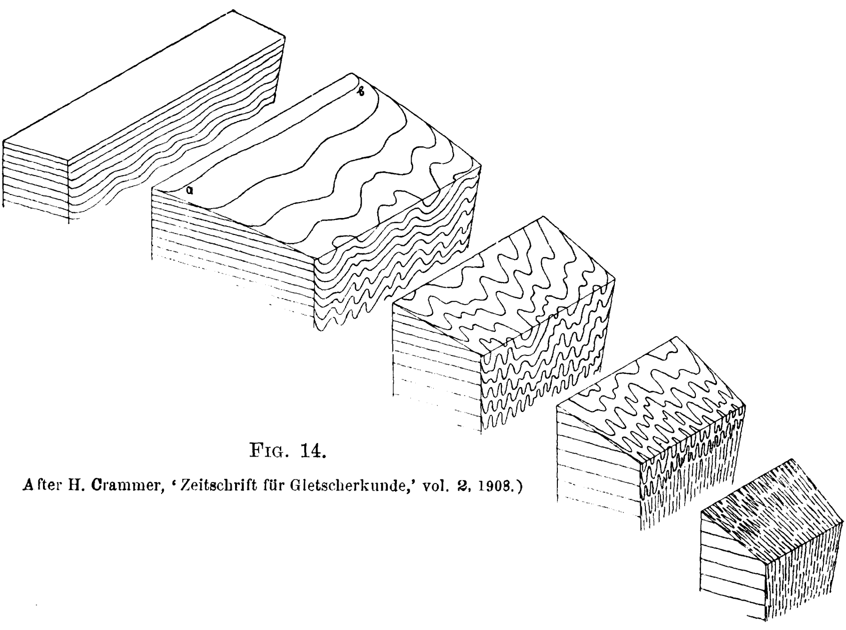

FIG. 14.

After H. Crammer, 'Zeitschrift für Gletscherkunde,' vol. 2, 1908.)

deformation, both horizontal and vertical (cf. Figs. 1 and 2). Thus the bands due to the scars of crevasses or shear planes also take a spoon shape near the glacier foot. In Fig. 16, AEF is a longitudinal section of a glacier foot, ABCD shows the probable form which the bands would have if their upper parts were not removed by ablation. Between AG and BH are shown the successive positions of a transverse crevasse, and the curved lines beneath indicate the successive forms taken by a shear plane. Thus there are in the glacier tongue two

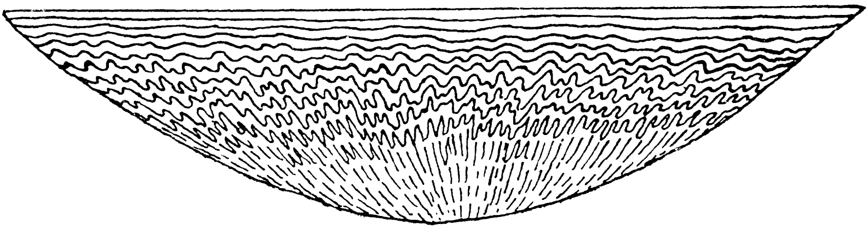

Fig. 15.

(After H. Crammer, 'Zeitschrift für Gletscherkunde,' vol. 2, 1908.)

distinct sets of bands which may have the form of spoons—the one, due to transverse crevasses, and the other, the transformed strata. The two sets often cut each other at very small angles.

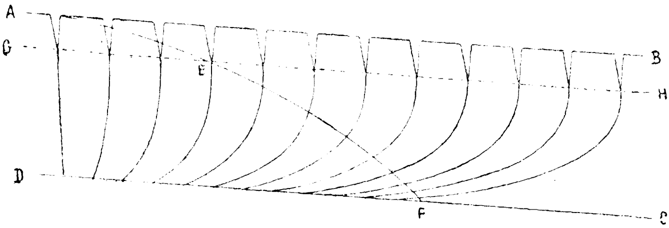

Fig. 16.

(After H. Crammer, 'Mitteilungen der Geographischen Gesellschaft,' Munich, vol. 4, 1909.)

S. Finsterwalder has recently described another type of *blätter*, or foliated structure in the ice, which he observed round the margin of a portion of the rock-bed, exposed by abnormal melting in the middle of the lower *névé* in the Vernagtferner. This foliation only appeared in the immediate neighbourhood of the rock-bed; it was very much contorted, and the leaves were from 1 millimetre to 5 millimetres in thickness. Finsterwalder thinks that this structure is produced quite independently of the *névé* stratification, and that it was probably the result of the movement. It may be considerably affected by the great local variations of pressure—due to differences in the thickness of the ice—which Finsterwalder believes to exist.

Theories concerning the Flowing Motion of the Ice.—There is a great difference of opinion with regard to the relation between the various ice structures and the movement of the glacier.

Hagenbach-Bischoff showed that the growth of the grains was due to the absorption by the bigger grains of the molecules from the smaller. Crammer has made experiments with the ice which he believes prove this to be true.

Below a certain depth the temperature of the ice is at the melting point which corresponds to the pressure. The differential motion must take place either between separate molecules—almost as in the case of a liquid—or else between groups of molecules.

Hess and Crammer agree that movement can take place only in a very slight degree between the surfaces of the granules, which, through the greater part of their course, are interlocked in a most irregular way.

Crammer is of opinion that in the *névé* the movement takes place mainly between the strata, and in the tongue between the bands or "leaves" (Blätter). He believes the movement to be greatly facilitated by the thin layer of dust which frequently exists between the strata. This, he says, prevents the grains of one layer from joining ("überkrystallisieren") those of another.

This view is supported by a recent observation of S. Finsterwalder on the Vernagtferner. In a depression in the otherwise bare ice surface an unusually great accumulation of winter snow was seen. This never melted, and it formed a small "inlier" of *névé* in the dissipator. It had no structure except the stratification of successive accumulation. This included mass was being carried downstream with the velocity of the veined ice upon which it lay. The lower part of the inlier was found to be striped, in the direction of flow, by fine lines of darker colour, which proved to be the outcrops of vertical cracks, or faults. These faults in the included *névé* were in prolongation of the veined structure of the underlying glacier. This minute faulting can only have been produced, in the opinion of Finsterwalder, by a differential gliding motion along the surfaces of the "leaves" (*blätter*) below. This gliding motion appears to take place by fits and starts, and to be in intimate relation with the formation of crevasses.

The researches which E. v. Drygalski made upon the inland ice of Greenland led him to believe that the movement is principally due to variations in pressure. Successive changes of pressure produce melting and regelation, which facilitate motion in a mechanical and molecular way.

Hess remarks that the physicists have proved the quality of plasticity to exist in a crystal of ice undergoing deformatory pressure, and it has even been suggested that a glacier composed of a single crystal would be able to move in much the same manner as one composed of grains. According to Hess, "the plasticity which enables the ice to flow is a character depending upon the action of molecular forces, and is due neither to the grained structure nor to the temperature conditions, though it is favoured by both these circumstances."

R. M. Deeley, who has made extensive optical and other studies of glacier ice, believes the differential motion results from :—

(1) The viscous shear between adjacent granules.

(2) The viscous shear along planes at right angles to the optic axis of the granules.

(3) The plastic shearing of the granules into separate pieces, and to the viscosity imparted to the general mass by the growth of one crystal at the expense of another—*i.e.*, by the interchange of molecules from grain to grain.

R. F. Tarr during his investigations on the variations of glaciers—a subject too big for discussion here—has been led to the conviction of the viscosity of the ice, at least below a certain depth.

Both Hess and Deeley lay stress upon the importance, for glaciology, of the study of the alteration of form undergone by metals at ordinary temperatures.

Chamberlain and Salisbury advance the view that the gliding planes within crystals play a notable rôle in the movement only in the basal parts of the lower ends of glaciers, *i.e.* where the granules are most completely interlocked. In other parts there is differential motion between the grains. This motion in the upper parts of the *névé* has no obstacle as the granules are more or less spherical and can slip over one another. The amount of relative change of position of the granules necessary to produce movement through the entire glacier is shown to be extremely small. This relative movement of the granules

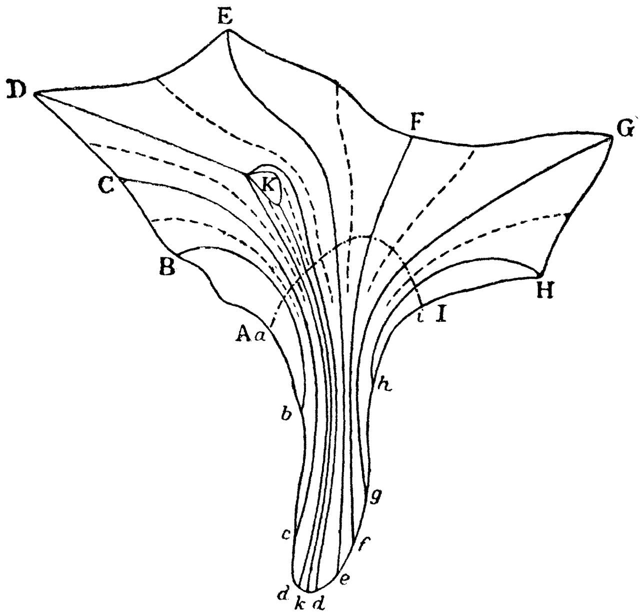

FIG. 17.

—·—·—·— = Névé line.

(After Finsterwalder, 'Zeitschrift des D.u.Ö. Alpenvereins, Wissenschaftliche Erganzungshefte,' vol. 1, No. 1.)

is chiefly due, they say, to the temporary passage of minute particles to the liquid state while the ice as a whole remains rigid.*

* For further information on properties of glacier ice, see the papers by J. Y. Buchanan mentioned in the Bibliography.

An account has recently been given (*Zeitschrift f. Gletscherkunde*, April, 1912) by the late Prof. Tarr and Dr. Rich of a series of experiments carried out by them on the properties of ice under pressure. No general conclusions are given by the authors, as the experiments were regarded as preliminary to further study, but among the many facts of interest which seem to be clearly demonstrated by the work, the following may be mentioned: (1) Ice which has undergone cutting by pressure, and subsequent regelation is optically undisturbed. (2) The deformation which ice undergoes when subjected to pressure is in the nature of plasticity; that is, a certain minimum stress is required for its initiation. Until this stress is reached there will be no permanent deformation. This plastic yield point lies near the breaking point of the ice. (3) The ease with which deformation may be produced varies with the direction in the crystal, and the effect of the deformation upon the optical properties also depends upon the direction. (4) Granular ice, composed of interlocking crystals, is subject to deformation equally with a single ice crystal. (5) In some directions the crystal will break by shearing before plastic deformation sets in. (6) Ice readily flows under pressure. (7) Snow can be changed to granular ice by pressure.

Transport of Moraine Matter.—The directions of movement in the different parts of the glacier ought to find illustration in the observed movement of moraine matter as given by the moraines. Finsterwalder's theory of moraines is the natural consequence of his theory of glacier flow (Figs. 6 and 7).

The rock *débris* which falls on to the *névé* margins passes along the bottom and is transported with the under-surface of the ice as ground moraine.* This material is ejected in the dissipator all round the margin and thus forms both lateral and terminal moraines. The lateral moraines are also in part composed of *débris* which has fallen upon the surface of the dissipator.

If there is an island in the reservoir, as K in Fig. 17, the *débris* formed there must follow the lines of flow downwards, and there will be no appearance of a line of moraine along the surface of the glacier starting from the island. On the other hand, where the material, coming from an island is situated either partly in the ablation area, as in Fig. 18, or wholly in it, the material that comes from the island will appear at once on the surface as a "medial" moraine, for the lines of flow are here coming to the surface. This medial moraine contains material both of the ground moraine and from the island.

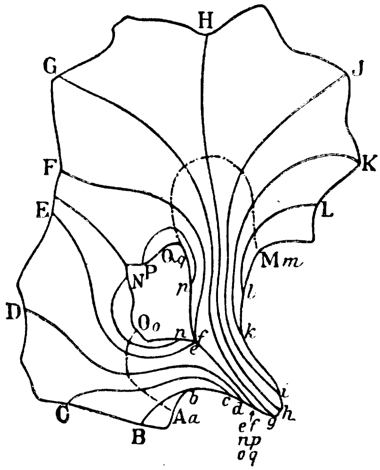

FIG. 18.

— · — · — · — = *Névé* line.

(After Finsterwalder, 'Zeitschrift des D.u.Ö. Alpenvereins, Wissenschaftliche Ergänzungshefte,' vol. 1, No. 1.)

Applying to the case of the island in Fig. 18 the principle illustrated in Fig. 19, Finsterwalder's theory would explain the non-appearance of moraine on the surface of the ice leaving K, by its passing along the flow-line till that line, after crossing the *névé* line, eventually reaches the surface where the overlying ice has been melted away.

For a medial moraine to be produced it is not necessary that an excrescence of the bed should be visible at the surface. Fig. 19 shows flow-lines of three different tiers, selected in relation to a rock obstruction in the bed of a glacier. In (1) the flow-lines are those starting from the edge of the *névé* and passing along the bottom of the bed; the *débris* from the obstruction at this level passes along the bottom throughout (cf. Fig. 7), and emerges only at the glacier front at "ab." In (2) the flow-lines are those of a tier nearer to the surface of the glacier; the *débris* from the margin of the higher part of the obstruction that is here embraced emerges at "cd" where it becomes a surface moraine. In (3) the flow-lines drawn are those which just catch the tip of the obstructing prominence, well under the surface of the glacier; the fragments which come from "E" emerge as surface moraines at "e." Thus the medial moraine from "e" to "ab" at the foot of the glacier is formed by the emergence of internal moraine, beginning with that from the tip of the rock "E" and growing by later additions from successively deeper levels of the rock obstruction.

* According to those glaciologists who maintain that the glacier is an active agent of erosion, the ground moraine has in its composition material "plucked" from the glacier bed.

Considering the three sections together; from the rock edge BDE runs the internal moraine—a vertical wall of *débris* extending to the ground. The nearer this moraine gets to the glacier foot more and more of it appears at the surface. Thus, all surface medial-moraines which depend upon the ground moraine for their material must increase in bulk as they approach the glacier front.

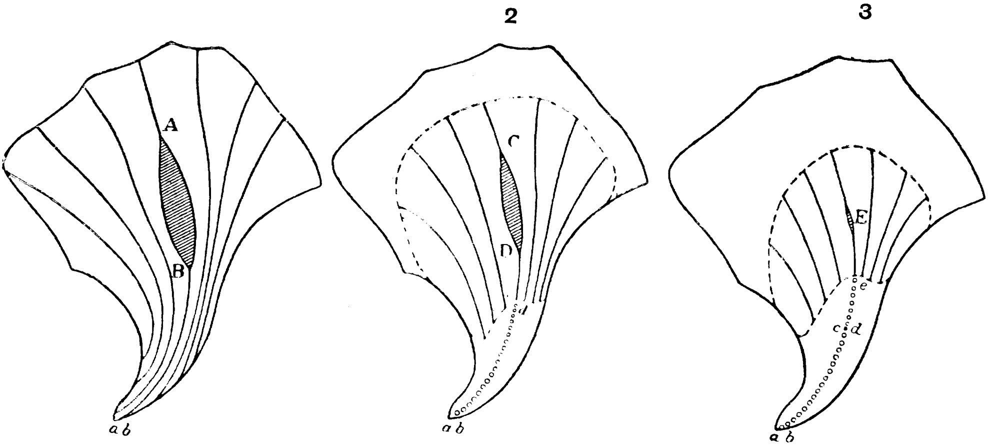

FIG. 19.

(After Finsterwalder, 'Zeitschrift des D.u.Ö. Alpenvereins, Wissenschaftliche Ergänzungshefte,' vol. 1, No. 1.)

Fig. 20—from Hess—shows the positions of the various types of moraine in a cross-section near the glacier end. Transverse moraines (T) which sometimes form, come, according to Hess, from the ice-falls of steep steps in the glacier bed.

Crammer, in developing his theory above mentioned, suggests how some of

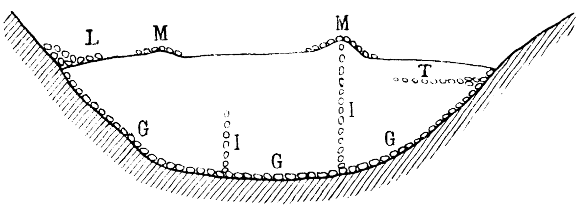

FIG. 20.

L = Lateral moraine.
G = Ground ,,
I = Internal ,,
M = Medial ,,
T = Transverse ,,
(After Hess, 'Die Gletscher.')

the ground moraine may become internal moraine. This material, he says, which is wedged into the lowest ice strata by vertical pressure, remains in the strata during their intense folding by the lateral pressure, and so eventually a bed of *débris*, formerly horizontal, may, like the strata, take up a vertical position.

BIBLIOGRAPHY.

L. AGASSIZ.—'Système Glaciaire.' Paris, 1847.

J. Y. BUCHANAN.—(*a*) "On Ice and its Natural History," *Proc. of Roy. Inst. of Gt. Brit.*, 1908, vol. 29.

(*b*) "Beobachtungen über die Einwirkung der Strahlung auf das Gletschereis," *Verhandl. der Naturf. Gesellschaft. Basel*, 1910.

(*c*) "In and around the Morteratsch Glacier," *Scottish Geog. Mag.*, April, 1912.

CHAMBERLIN and SALISBURY.—'Geology,' vol. 1, 1904.

HANS CRAMMER.—(*a*) "Ueber den zusammenhang zwischen Schichtung und Blätterung, und über die Bewegung der Gletscher," *Zentralblatt f. Mineralogie*, etc., 1902.

(*b*) "Eis und Gletscherstudien," *Neues Jahrbuch für Mineralogie*, etc. Supplement, 1903.

(*c*) "Ueber Gletscherbewegung und Moränen," *Neues Jahrbuch für Mineralogie*, etc., 1905; vol. 2.

(*d*) "Die Gletscher," *Aus der Nature*, 1906.

(*e*) "Ueber Klüfte im Firnfeld," *Zeitschrift für Gletscherkunde*, vol. 2, 1908, p. 61.

(*f*) "Zur Entstehung der Blätterstruktur aus der Firn. schichtung," *Zeits. für Gl.*, vol. 2, 1908, p. 198.

(*g*) "Struktur und Bewegung des Gletschereises," *Mitteilungen der Geograph. Gesellschaft, Munich*, vol. 4, 1909.

R. M. DEELEY.—(*a*) "The Structure of Glacier Ice," *Geolog. Magazine*, Dec., 1907.

(*b*) "Glacier Granule Markings," *Idem*, March, 1910.

(*c*) "The Structure of Glaciers," *Idem*, Oct., 1910.

(*d*) "Glacier Motion," *Idem*, Jan., 1911.

E. v. DRYGALSKI.—(*a*) 'Die Grönlandexpedition der Berliner Gesellschaft für Erdkunde.' Berlin, 1897.

(*b*) "Spitzbergens Landformen," *Kgl. Bayerisch. Akad. der Wissenschaften*, vol. 25, 1911.

S. FINSTERWALDER.—(*a*) "Der Vernagtferner," *Deutsch und Oesterreichischer Alpenverein*. Scientific Supplement, 1. 1897.

(*b*) "Ueber die innere Struktur der Mittelmoränen," *Kgl. Bayerisch. Akad. der Wissenschaften*, vol. 30, 1900.

(*c*) "Beobachtungen über die Art der Gletscherbewegung." *Kgl. Bayerisch. Akad. der Wissenschaften*, 1912.

F. A. FOREL.—"Structure Rubanée," *Zeits. f. Gletscherkunde*, vol. 1, 1906.

HAGENBACH-BISCHOFF.—(*a*) "Das Gletscherkorn," *Verhandl. der Naturf. Gesellschaft Basel*, 1888.

(*b*) "Gletschereis," *Idem*, 1889.

A. HAMBERG.—"Ueber die Parallelstruktur des Gletschereises," *IX. Congrès intern. de Géographie. Genève*, 1908. *Compte rendu*, t. II.

H. HESS.—(*a*) "Ueber den Zusammenhang zwischen Schichtung und Bänderung," *Neues Jahrbuch f. Mineralogie*, etc., 1902.

(*b*) "Probleme der Gletscherkunde," *Zeits. f. Gletscherkunde*, vol. 1, 1907.

(*c*) 'Die Gletscher.' Brunswick, 1904.

P. MERCATON.—'La III. Conférence Glaciaire Internationale,' *Archives des Sciences Phys. et Nat.*, Genève, 1905.

CH. RABOT.—"Revue de Glaciologie, 1903–1907," *Mém. de la Soc. Fribourgeoise d. Sciences Nat.*, V.

H. F. REID.—(*a*) "The Mechanics of Glaciers," *Journal of Geology.* Chicago, 1896.
(*b*) Compte Rendu du VIII., Congrès Geolog. Internat. 1900. Paris.
(*c*) „ „ IX. „ „ „ 1903, Vienna,
(*d*) "Flow of glaciers and stratification," *Appalachia,* XI.

R. S. TARR.—"Theory of Advance of Glaciers in Response to Earthquake Shaking," *Zeits. f. Gletscherkunde,* V., 1910.

R. S. TARR and J. L. RICH.—"The Properties of Ice—Experimental Studies," *Zeitschrift für Gletscherkunde,* vol. 6, 1912, p. 225.

THE ATLANTIC AND PACIFIC TYPES OF COAST.

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PROF. J. W. Gregory has recently * drawn attention to apparent contradictions in Prof. Suess' definitions of the two main types of coast exhibited on the globe, and the result of his inquiry is that, according to him, the original definitions should be modified. Taking the coast-lines of the world one by one and examining their history and position, it would appear that Prof. Suess' definitions explain so much and are so illuminating that it seems a pity to discredit them by bringing to bear on the question, which is one of broad outline, details which confuse the issue. According to Prof. Suess, the Atlantic is bordered by folded mountain chains which run out to sea and are cut off by the coast-line; the Pacific by folded mountain chains which run parallel to the coast-line. In addition, the folds of the Atlantic expose their backs to the ocean, and those of the Pacific their fronts; in other words, if the range is composed of Archæan, Palæozoic, and Mesozoic strata, the old Archæan base is exposed on the Atlantic side and the youngest strata on the Pacific side. A good example of this latter fact is represented by New Zealand and South Africa. In South island in New Zealand the folded ranges come from the north-east and meet on the south-west in a knot or *Schaarung* with the folds which come from the south-east. In the embrace of the folds lies a plateau of Mesozoic strata corresponding to the Karroo beds of South Africa, whereas on the side of the island facing the mainland—that is, Australia—the Archæan base is exposed. In South Africa the exact reverse is represented; the Karroo beds lying in the angle of the Schaarung are inland, and the Archæan base of the coastal mountains faces the open ocean.

There is, however, water between New Zealand and Australia; that is, the true continental border of the western side of the Pacific is partly

* "The Structural and Petrographic Classifications of Coast-Types," *Scientia* vol. 11, 1912.